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TECHNICAL NOTE

No. 952

A UNIT LABORATORY ENGINE OIL SYSTEM PROVIDING FOR A
REMOTE INDICATION OF OIL FLOW AND OIL CONSUMPTION
TOGETHER WITH BLOW-BY MEASUREMENT

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SUMMARY

A unit oil system and oil-weighing device designed for laboratory engine tests to permit the remote measurement of oil-flow rate and oil consumption is described. The system regulates the oil pressure and temperature and is closed to make possible the accurate measurement of blow-by gas. The oil is weighed by a self-contained diaphragm and pilot-valve assembly, which uses compressed air as the transmitting medium. Several of these unit systems have given satisfactory service for more than a year.

INTRODUCTION

A unit oil system and oil-weighing device for laboratory test engines was developed during 1942 and 1943 by the Fuels and Lubricants division of the NACA. The object of this development was to provide an accurate semiportable laboratory oil system of the closed type for the measurement of blow-by gas and the elimination of fumes. A remote means of indicating oil flow and oil consumption was provided in order that the oil system might be placed below the test engine to permit the use of a gravity oil return, which would obviate the need for a scavenge pump with its consequent foaming.

SINGLE-CYLINDER-ENGINE OIL SYSTEM

A single-cylinder-engine oil system with connections to the test engine and closed piping circuit for blow-by measurement is shown schematically in figure 1. The main components of the oil system are oil-weighing tank and weighing-diaphragm assembly, oil pump, oil-temperature-regulator system, and oil strainer. Oil flows by gravity, or is pumped from the engine sump to the top of

the oil-weighing tank from which it flows by gravity, to the lower compartment. It is then pumped by a gear pump through the oil heater-cooler system, which regulates the oil temperature, and then back to the engine through a combined oil strainer and manifold, which supplies lubricant to the various engine bearings and spray jets. It will be noted that, although all the oil passes through the oil heater, the flow divides on its way to the temperature-regulating valve, some going through the oil cooler and the rest flowing directly to the temperature-regulating valve.

The heating elements of the oil heater have a low-wattage dissipation per unit surface area to avoid local overheating with consequent deterioration of the oil. A thermoswitch at the outlet of the oil heater turns off the heater when the temperature of the oil reaches the desired value.

For automatic temperature control, valves 1 and 3 (fig. 1) are closed and valves 2 and 4 are opened; this operation passes both hot and cold oil through the thermostatic mixing valve and over its active control element. The automatic temperature setting is adjusted by turning the stem of the thermostatic mixing valve (fig. 2). Manual temperature control is obtained by closing valves 2 and 4 and setting valves 1 and 3 in such a way that the desired temperature is maintained by mixing the hot and the cold oil.

Oil pressure to the engine is regulated by a pressure-relief valve that discharges into the top of the lower compartment of the oil-weighing tank. The safety pressure-relief valve, shown in figure 1, is set at approximately 40 pounds per square inch to avoid excessive pressures in the oil cooler caused by the forcing of cold oil through the cooler or the accidental closing of the temperature-regulating valves.

The warm-up bypass valve near the test engine (fig. 1) is opened before starting the engine in order that the oil can flow back to the oil-weighing tank and pass through the heater again; thus the oil warm-up time is reduced. This valve is closed before the engine is started to bring the engine oil pressure and flow to normal. The engine warm-up time is greatly reduced by the circulation of hot oil through the crankcase.

The entire oil system is closed in order that blow-by gases can be led from the sealed crankcase through a blow-by tube to a blow-by meter. When a scavenge pump is used on the engine, the pressure-equalizer tube (fig. 1) should be of such a size as to eliminate surging of the weighing manometer. On engines such as

the Cooperative Universal type equipped with a cylinder of about 200-cubic-inch displacement it has been found that this tube must be at least 1 inch in diameter. In some instances it has been found necessary to provide a surge tank in the crankcase blow-by system to prevent fluctuations in the blow-by manometer. The surge tank in this case would be inserted in series with the blow-by tube shown in figure 1. This surge tank is most likely to be necessary on single-cylinder engines made by modifying a multicylinder engine crankcase.

Figures 2 and 3 demonstrate the compact arrangement of the single-cylinder-engine oil system and its oil-weighing tank. The unit system is mounted on an angle-iron base and may be placed beside an engine on the bedplate, if the engine has its own sump pump, or under the floor away from the test setup. This unit oil system is adaptable to various laboratory tests because it has its own oil pump and means of pressure and temperature control and because the weighing tank serves as the oil reservoir. A flexible power cable is connected to any convenient outlet to supply power for the oil pump and the oil heater. Cooling water can be supplied to the oil cooler through a hose or a pipe. The temperature of the water leaving the oil cooler is regulated by a thermostatic water regulator (not shown in figs. 2 and 3), which minimizes the amount of cooling water required.

The four temperature-regulating valves and the thermostatic mixing valve are arranged in one vertical plane in order that manual-control shafts for conveniently operating these valves can be most readily extended to the control bench if the unit is located under the floor. The pump and the heater are remotely controlled by a seven-wire cable that connects into the side of the motor starter box. This cable leads to two start-and-stop switches mounted on the control panel. The switches are so wired that the oil heater cannot be turned on unless the oil-pump-motor current is on. A green pilot light indicates that the pump-motor current is on and a red pilot light indicates that the heater current is on.

The unit oil system described can be used, with slight modification, on engines that have their own pressure and scavenge pumps. In such cases a bypass valve must be installed around the relief valve used for setting the engine-oil pressure. The bypass valve is closed to circulate warm-up oil in the lines to and from the engine and is opened as much as necessary to lower the oil-in pressure to the engine pump before the engine is started.

OIL-WEIGHING-TANK ASSEMBLY

Operation. - The oil-weighing tank (fig. 4) is divided into two compartments connected to each other by an overflow pipe and a dump valve that is normally held open by a spring and closed by air pressure. Oil returning from the engine flows into the upper compartment and through the dump valve into the lower compartment.

The oil pressure in the lower compartment is balanced by the air pressure acting on the oil-weighing-diaphragm assembly (fig. 5) bolted to the side of the lower compartment near the bottom. The air pressure is proportional to the oil pressure at the weighing diaphragm and, because the lower compartment has a constant cross section, the air pressure is also proportional to the weight of oil above the diaphragm if the oil level is below the bottom of the upper tank compartment.

When the dump valve is closed by turning the three-way air cock (fig. 1), oil continues to flow from the engine into the upper compartment where it is stored; meanwhile, the pump removes oil at a steady rate from the reserve oil in the lower compartment. As oil is removed by the pump, the pressure at the weighing-diaphragm assembly drops. The corresponding drop in the balancing air pressure is observed on the weighing manometer in the control room. The manometer is timed as it drops a certain distance and its rate of descent is calculated in inches per minute. The corresponding oil-flow rate, in pounds of oil per minute, can be read from a calibration curve.

After the manometer descent has been timed, the three-way cock is returned to its original position and the dump valve releases the trapped oil to the lower compartment. The overflow pipe in the upper compartment is of such length that the oil in the upper compartment will overflow before the pump removes all the oil from the lower compartment. The engine will thus have an uninterrupted supply of oil in case the operator forgets to open the dump valve. The oil that flows through the dump valve or the overflow pipe is conducted by a cone to the walls of the lower compartment along which it flows to the main body of the oil in the compartment. In this way the escape of gases entrained in the oil is promoted and splashing of the incoming oil, which would cause the indicating manometer to bounce, is prevented. The pressures in the lower and the upper compartments are equalized by a tube extending from the apex of the cone through the overflow pipe to the top of the upper compartment (fig. 4).

A study of figures 1 and 4 shows that any oil flowing into the lower compartment from the engine oil-pressure-relief valve will

not affect the determination of the rate of oil flow to the engine. Similarly, if the total oil flow to the engine is divided and each flow rate is desired, the flows not being measured are returned to the lower compartment and will not affect the measurement of the flow rate being determined.

Oil consumption is obtained from the drop of the weighing-manometer column over a period of time. Initial and final manometer readings are taken at the same oil-flow conditions, and the amount of oil consumed is read from a calibration curve.

Design of tank. - The oil-weighing tank and the oil system described have been used on multicylinder engines with changes in the size of the component parts. For best results, the weighing tank should be designed for particular oil requirements of an engine. Several factors must be considered in designing a tank: oil-flow rate, maximum manometer-dropping rate that can be observed with sufficient accuracy, required accuracy of oil-consumption determinations, and reserve capacity of the tank between additions of oil. The tank should be so designed that, when the oil flow is measured, the indicating manometer should drop about 20 inches of water during the readings; the time required for such a descent should be about 40 seconds or longer. A smaller manometer drop or a more rapid rate of descent will cause inaccuracy.

Oil-weighing-diaphragm assembly. - The oil-weighing diaphragm and its pilot valve are part of a self-contained assembly (fig. 5) that is bolted to the side of the lower compartment of the oil-weighing tank. The oil pressure exerts an upward force on the diaphragm that is balanced by compressed air throttled by the poppet valve into the space above the diaphragm. As the oil pressure decreases, the diaphragm moves down, owing to an excess of air pressure, and opens the exhaust port formed by the lower tip of the pilot-valve stem and the conical seat in the end of the valve-adjusting screw. The excess air is then led back through drilled passages in the center stud of the diaphragm to a rubber tube exhausting to the atmosphere. Air pressure is thus reduced until the diaphragm moves back to its equilibrium position and both valve ports are closed. An increase in oil pressure opens the upper valve port and raises the pressure required without opening the lower port; therefore, the pressure above the diaphragm is always directly proportional to the oil pressure acting on the diaphragm. When the system is flushed and refilled with oil, it is necessary to bleed the air from the under side of the diaphragm, which is readily accomplished through the bleed plug shown in figure 5.

The poppet valve shown in figure 5 is closed by gravity and by a small unbalanced air pressure acting on its upper end. Inasmuch as the diameter of the valve port is $1/8$ inch and the maximum differential pressure acting on it is about 1.5 pounds per square inch, the unbalanced force on the valve stem has a negligible effect upon the sensitivity of the diaphragm. The slight taper of the upper valve face permits smooth descent of the manometer with no surging or hunting and, at the same time, allows the valve stem to adjust itself to a slightly eccentric diaphragm. The diaphragm fabric is cemented to the metal diaphragm disk. (See fig. 5.)

Another satisfactory weighing-diaphragm assembly is shown in figure 6. This diaphragm has an effective area of about 10 square inches and uses a balanced-pressure piston-ported spool valve. In operation, compressed air enters the upper port and is throttled into the central chamber, which is connected by drilled passages to the space above the diaphragm and to the space above the piston-spool valve. The operation of this weighing diaphragm is essentially the same as the weighing diaphragm shown in figure 5. The pilot valve shown in figure 6 has a flexible wire connecting it to its diaphragm in order to minimize side thrust caused by an eccentricity of the diaphragm.

Either type of pilot valve is initially adjusted to bring the diaphragm to its equilibrium position when the center of the diaphragm is in the same plane as its outside edge. This adjustment is made by turning the adjusting screw in the center stud shown in figure 5 or by changing the length of the connecting wire between the valve and the diaphragm shown in figure 6. The compressed-air supply should be filtered and regulated to a pressure of about 1 pound per square inch in excess of that necessary for the maximum manometer pressure.

Design of weighing-diaphragm assembly. - Diaphragm sensitivity increases as the square of the effective diameter and directly as the flexibility of the diaphragm fabric; therefore, a large effective area and a flexible fabric for accurate oil-consumption measurements are desirable. Nothing is gained by increasing the sensitivity of the diaphragm beyond the point where the percentage error in the readings of the air-pressure manometer will mask the improved diaphragm performance. The effective diaphragm area is assumed to be the area of a disk, the diameter of which is equal to the mean diameter of the flexible annular portion of the fabric. The flexible part of the diaphragms used in the apparatus described is about $3/4$ inch wide and the material is oil-resistant impregnated fabric having a thickness of $1/32$ inch.

Both the diaphragm assembly using the poppet valve (fig. 5) and the diaphragm assembly using the balanced-pressure piston-ported spool valve (fig. 6) have been satisfactory but, for small effective areas, the spool valve allows a more compact design because it does not need the special bleed tube to the atmosphere. The poppet valve is simpler to make and does not require the lapped surfaces that are necessary in the spool valve.

An application. - In certain tests it may be desirable to watch the oil consumption. Inasmuch as this type of oil-weighing device uses air as the transmitting medium, a pressure-against-time, strip-chart recorder can be used in parallel with the manometer. The change in oil consumption can thus be watched and its value computed from the slope of the curve. Oil-consumption readings are usually taken every 5 minutes for a 1/2-hour period when determining specific oil consumption.

CALIBRATION OF THE WEIGHING DEVICE

The weighing device was calibrated using a setup similar to that shown in figure 1, in which the test engine was replaced by a globe valve to vary the oil flow and a three-way plug valve to direct oil into a weighing pail or to return it to the upper compartment of the weighing tank. A stop watch was started as the manometer column passed the 13-inch mark and was stopped when the column passed the 3-inch mark. This 10-inch drop was chosen because oil would then be falling through an unobstructed part of the lower compartment and some oil would still remain above the weighing diaphragm at all times. The manometer was read to within ± 0.05 inch of water for both oil-flow rate and oil-consumption determinations. The hand timing was probably accurate within ± 0.2 second, and the oil was weighed to ± 0.5 ounce; all measurements were accurate to about 1 percent.

During the calibration of the oil-weighing device, oil consumption was simulated by pumping about 9.5 pounds of oil from the lower compartment, through the globe and the plug valves, and into a weighing pail. The drop in air pressure at the indicating manometer represented the pounds of oil removed. Both the initial and the final manometer readings were taken with the dump valve open and the oil flowing through the entire system just as though oil were being supplied to a running engine.

Figure 7 shows the relationship between the weighing manometer-dropping rate in inches of water per minute and the rate of oil flow in pounds per minute.

The pounds of oil per inch of water is plotted against the oil flow in pounds per minute in figure 8. The oil-flow rate has a slight influence on the oil-consumption factor. This effect, however, is very small for the usual variations in the rate of oil flow to an engine.

SUMMARIZATION OF DESIGN FEATURES

In the unit laboratory oil system providing for a remote indication of oil flow and oil consumption, together with blow-by measurement, the following features have been obtained:

1. A separate motor-driven pump is used to circulate the oil through the engine or the oil system before the engine is started.
2. Automatic oil pressure and temperature regulation are provided.
3. The oil temperature and pressure regulating apparatus and the oil-weighing device are incorporated in a semiportable unit with remote control.
4. The oil system is closed in order that accurate blow-by measurements can be made.
5. The oil-weight reading is remotely indicated and depends only upon weight of the oil. No effects of temperature upon the calibration of either oil-flow or oil-consumption rates were found within the limits of experimental accuracy when the temperature was varied from 165° F to 205° F.
6. The system is able to reproduce results within ± 2.5 percent for both oil-flow and oil-consumption determinations.
7. The weighing device maintains its calibration over long periods of time without attention. Experience has indicated a good stability of calibration; the device, however, requires a new calibration if the diaphragm assembly is taken apart.

8. The manometer gives a steady indication of oil weight and drops smoothly during flow-rate determinations. No trouble has been experienced with hunting at the low air pressures supplied to the pilot valve. Variations in supply air pressure of ± 0.5 pound per square inch had no effect on the manometer reading.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, August 5, 1944.

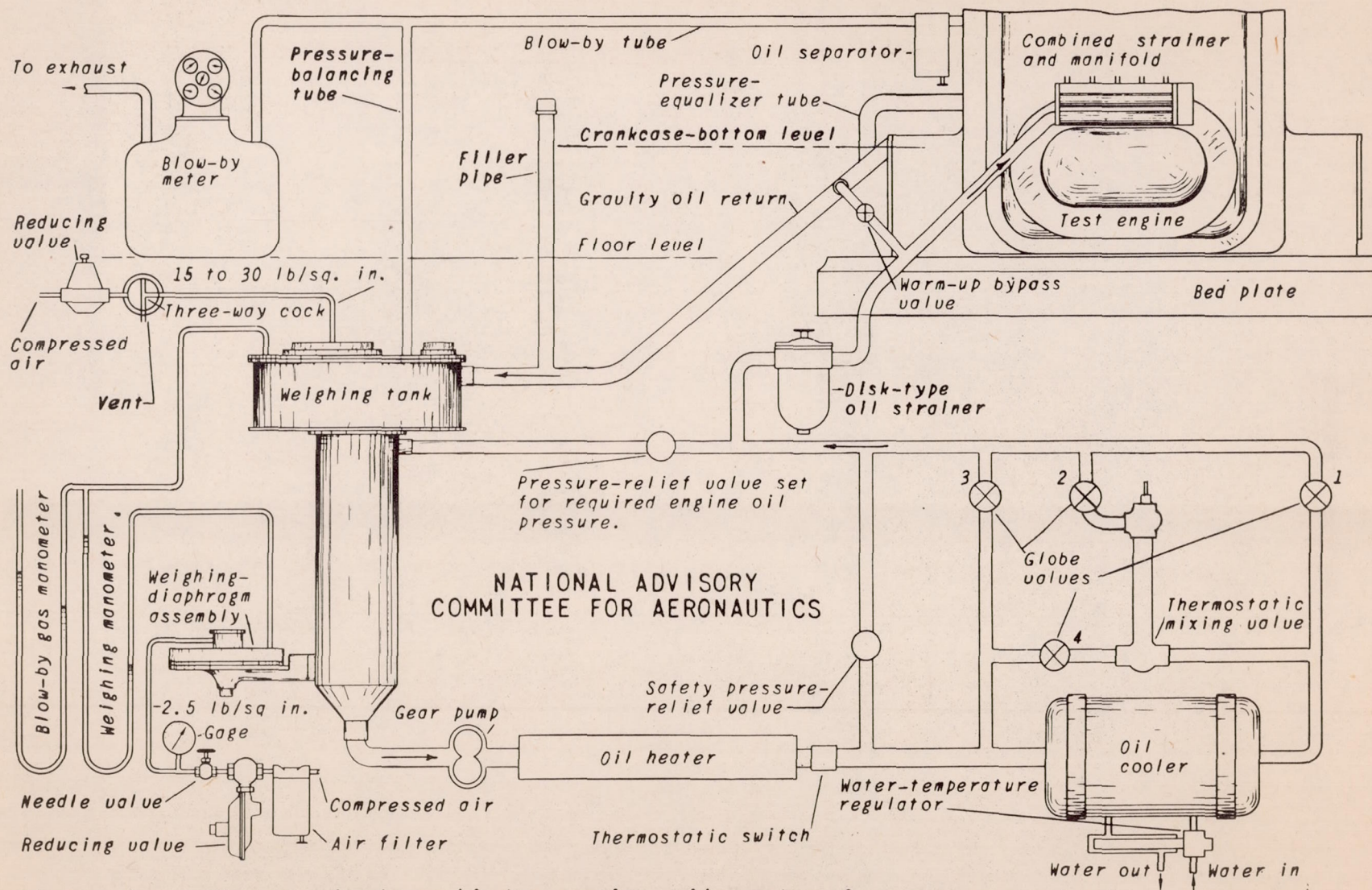
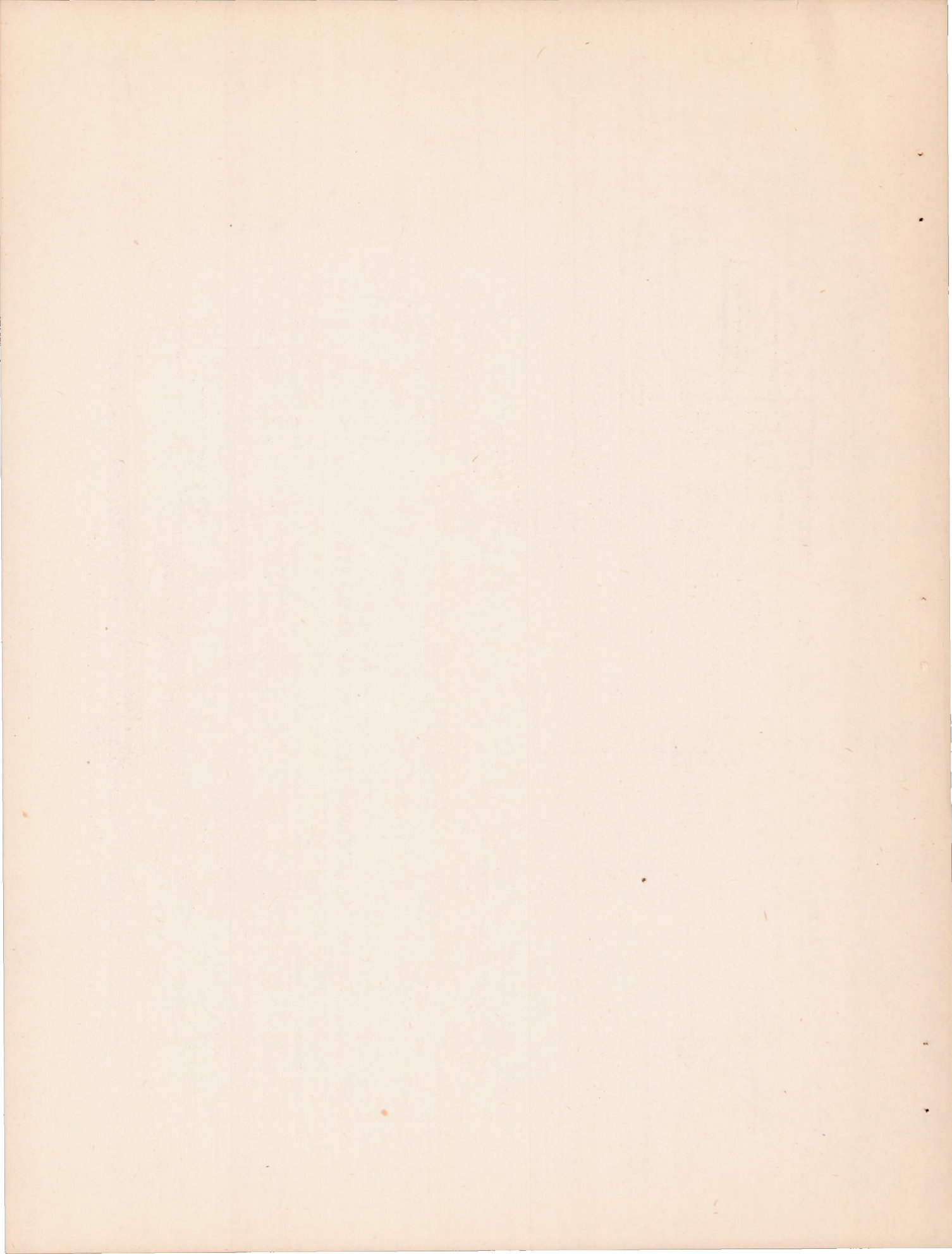


Figure 1. - Closed single-cylinder-engine oil system for measurement of blow-by gas, oil flow, and oil consumption.



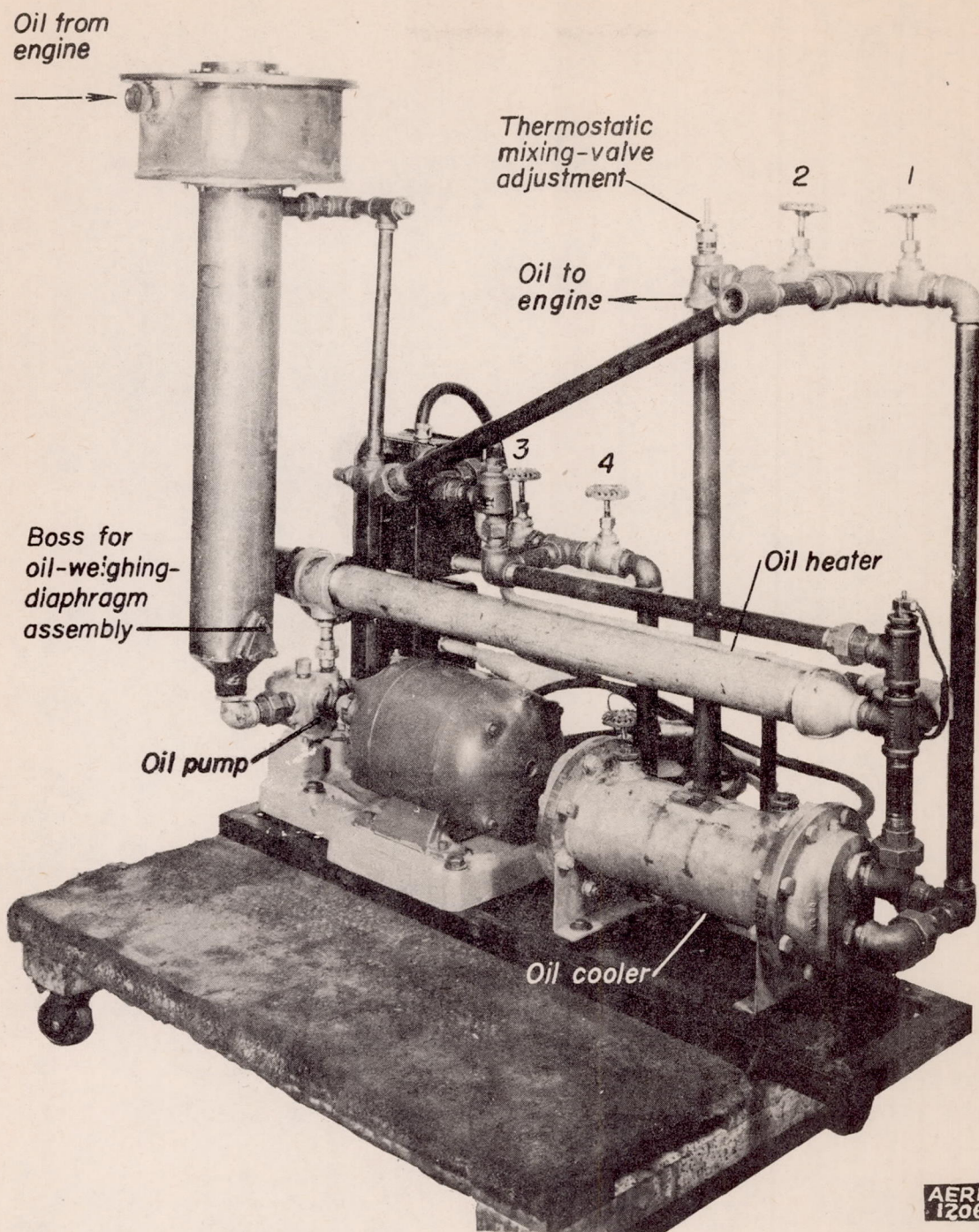
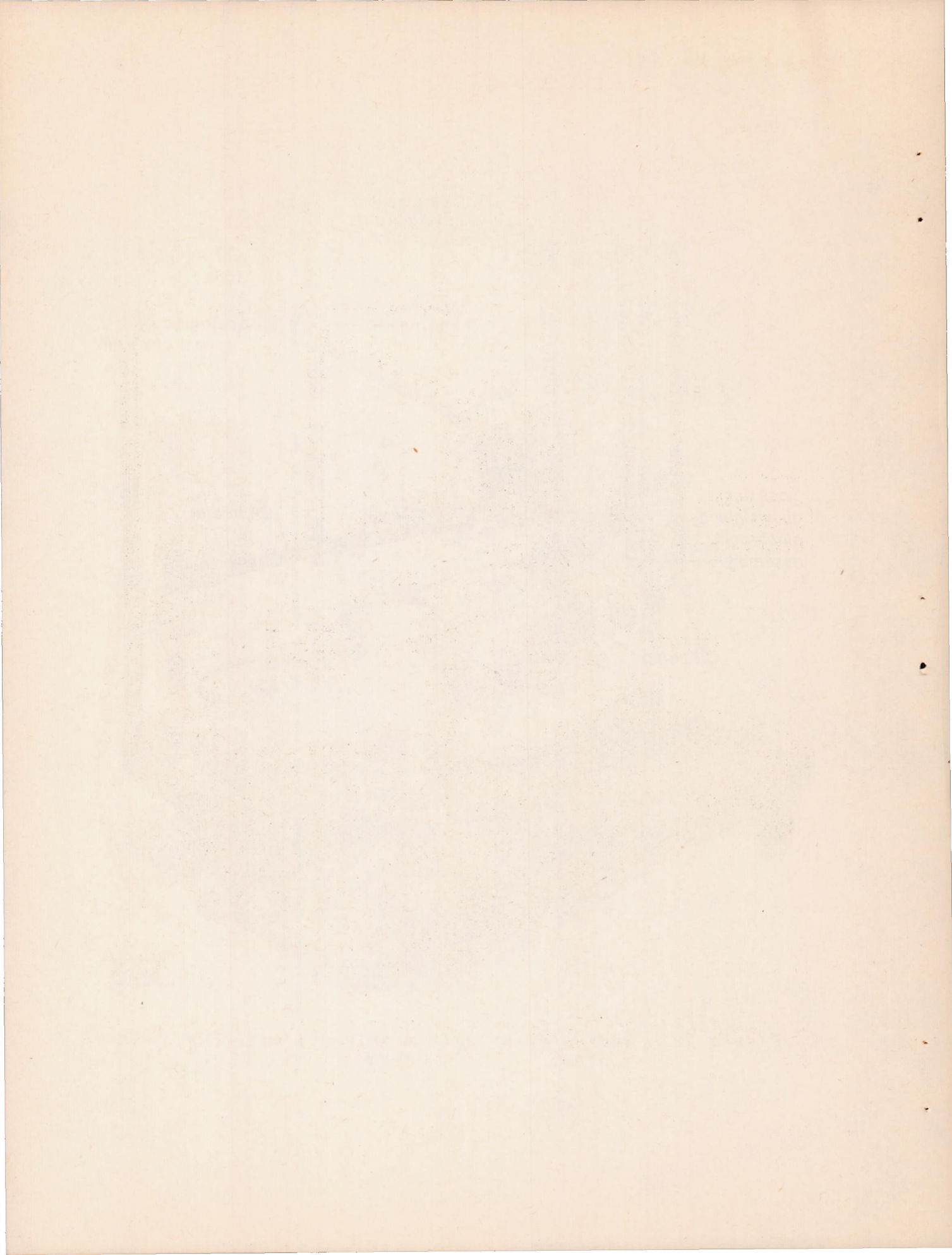
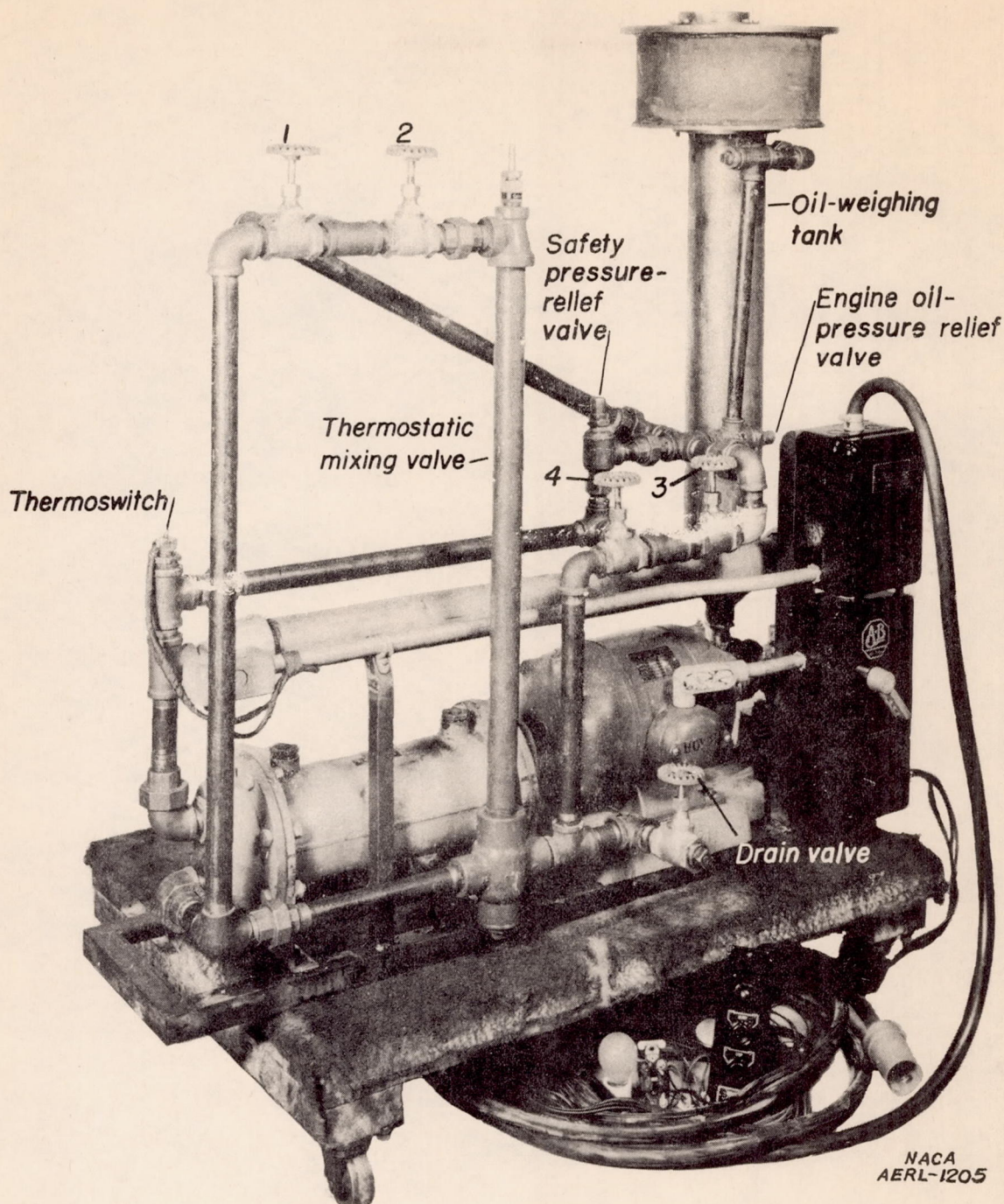


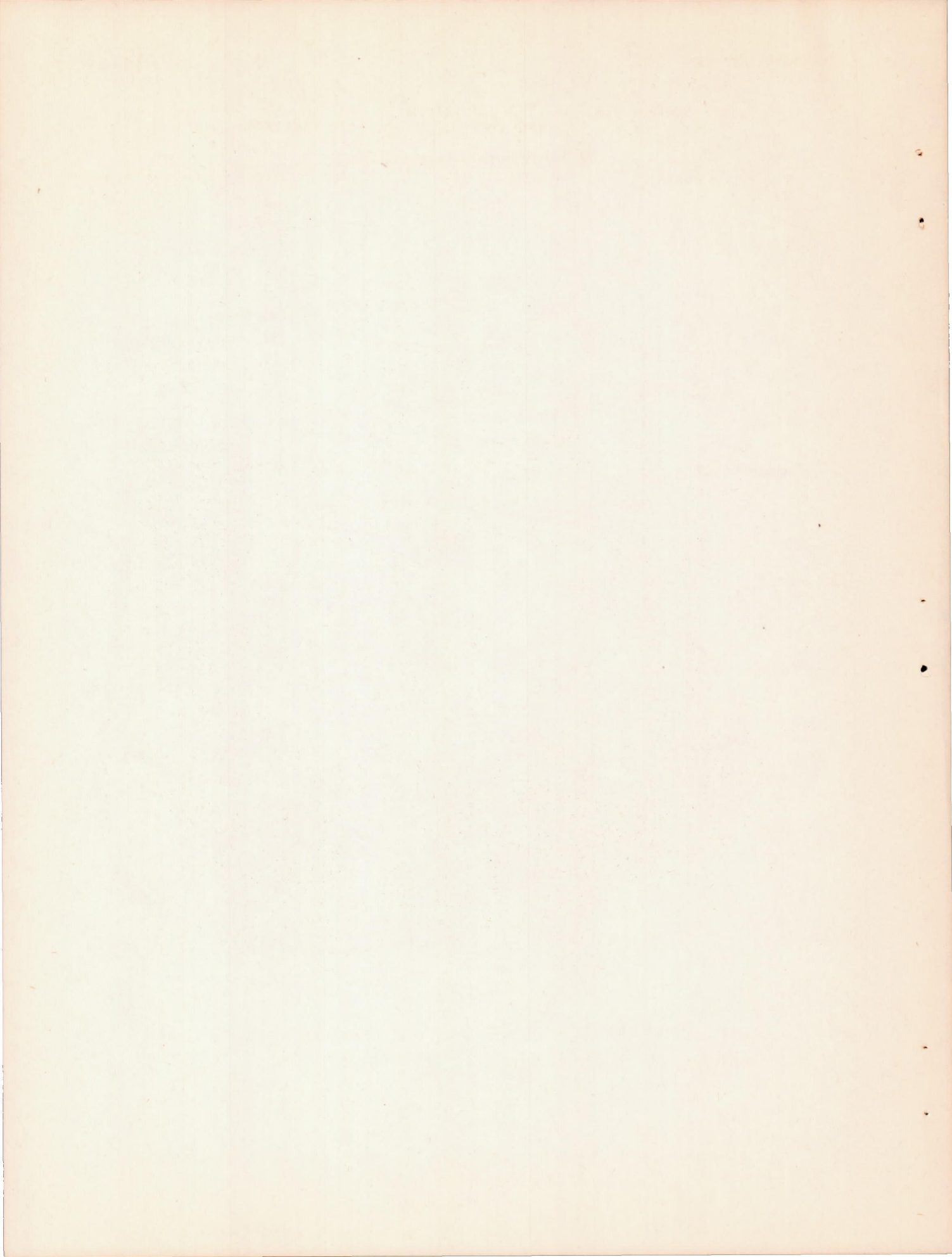
Figure 2. - Rear view of unit single-cylinder-engine oil system.





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Figure 3. - Front view of unit single-cylinder-engine oil system.



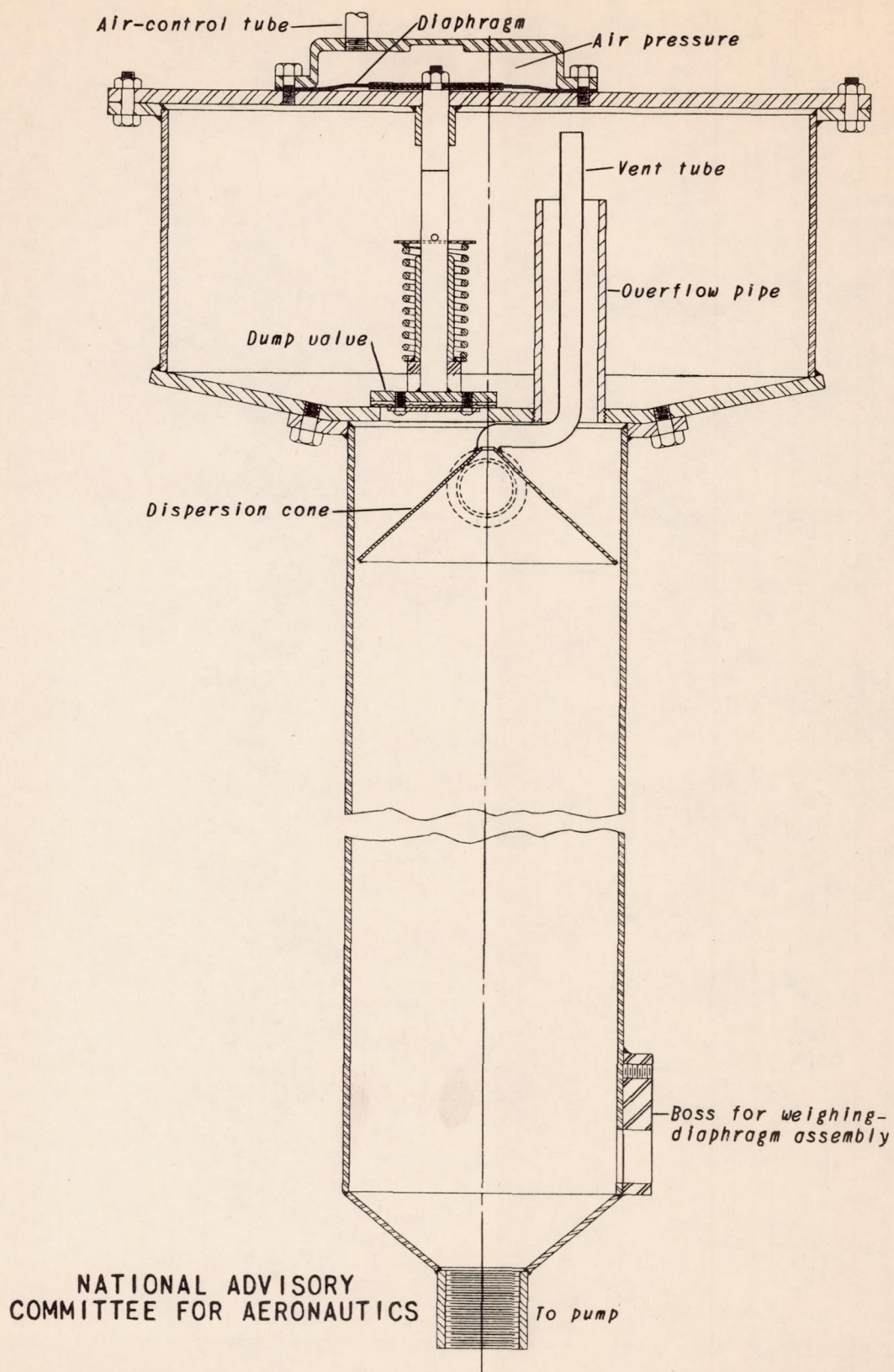
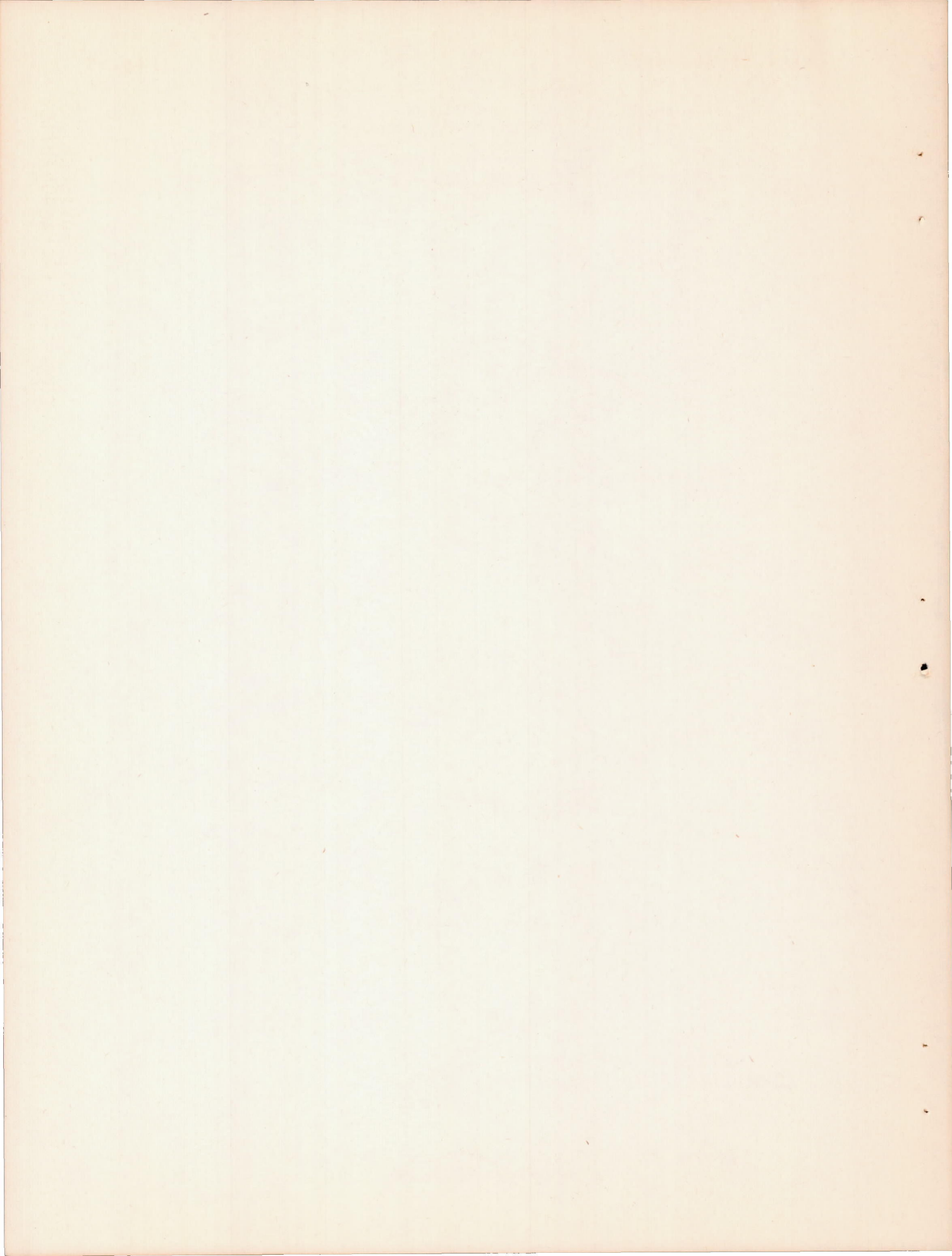


Figure 4. - Cross section of single-cylinder-engine oil-weighing tank.



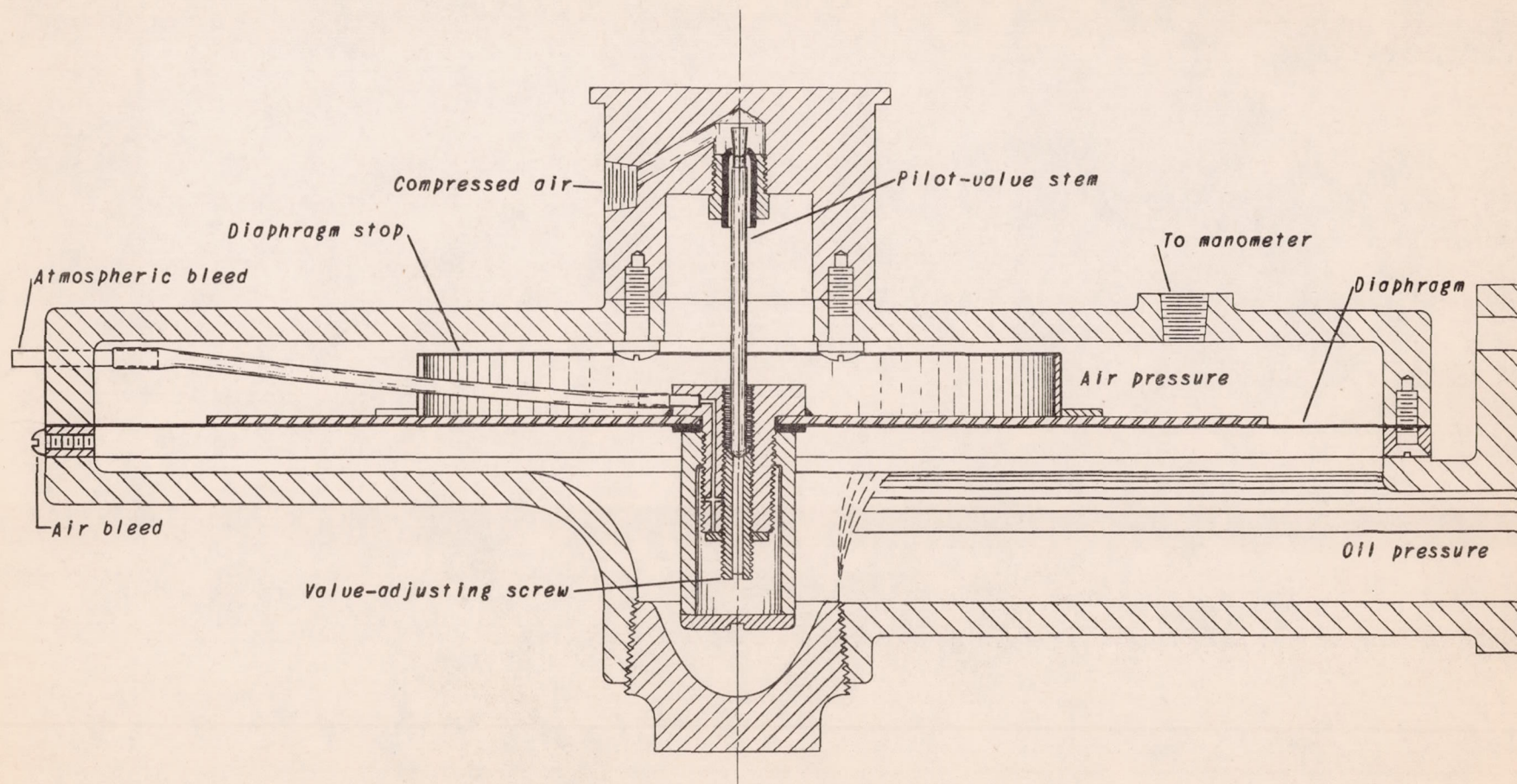
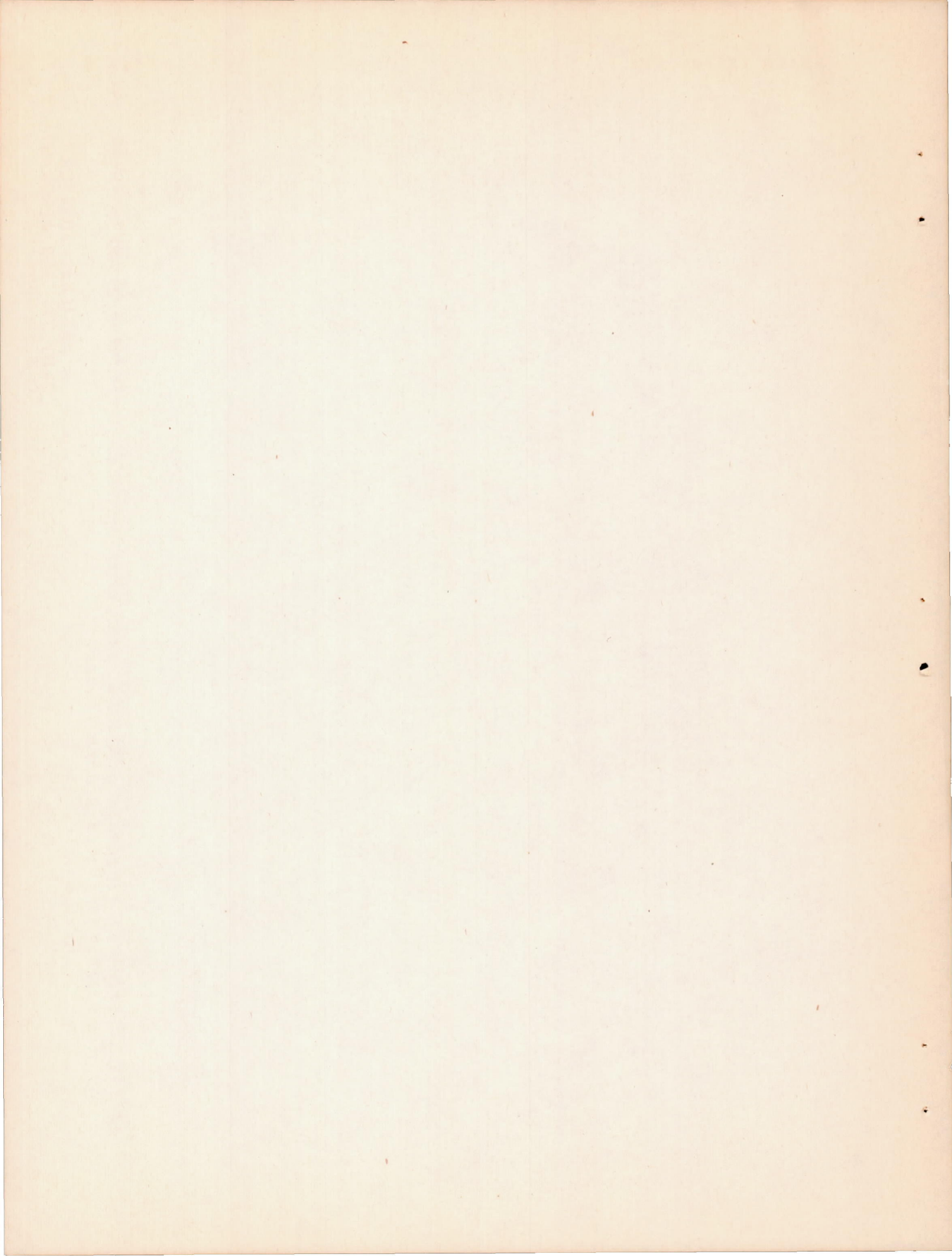


Figure 5. - Weighing-diaphragm assembly, poppet-valve type. Effective area, approximately 65 square inches.



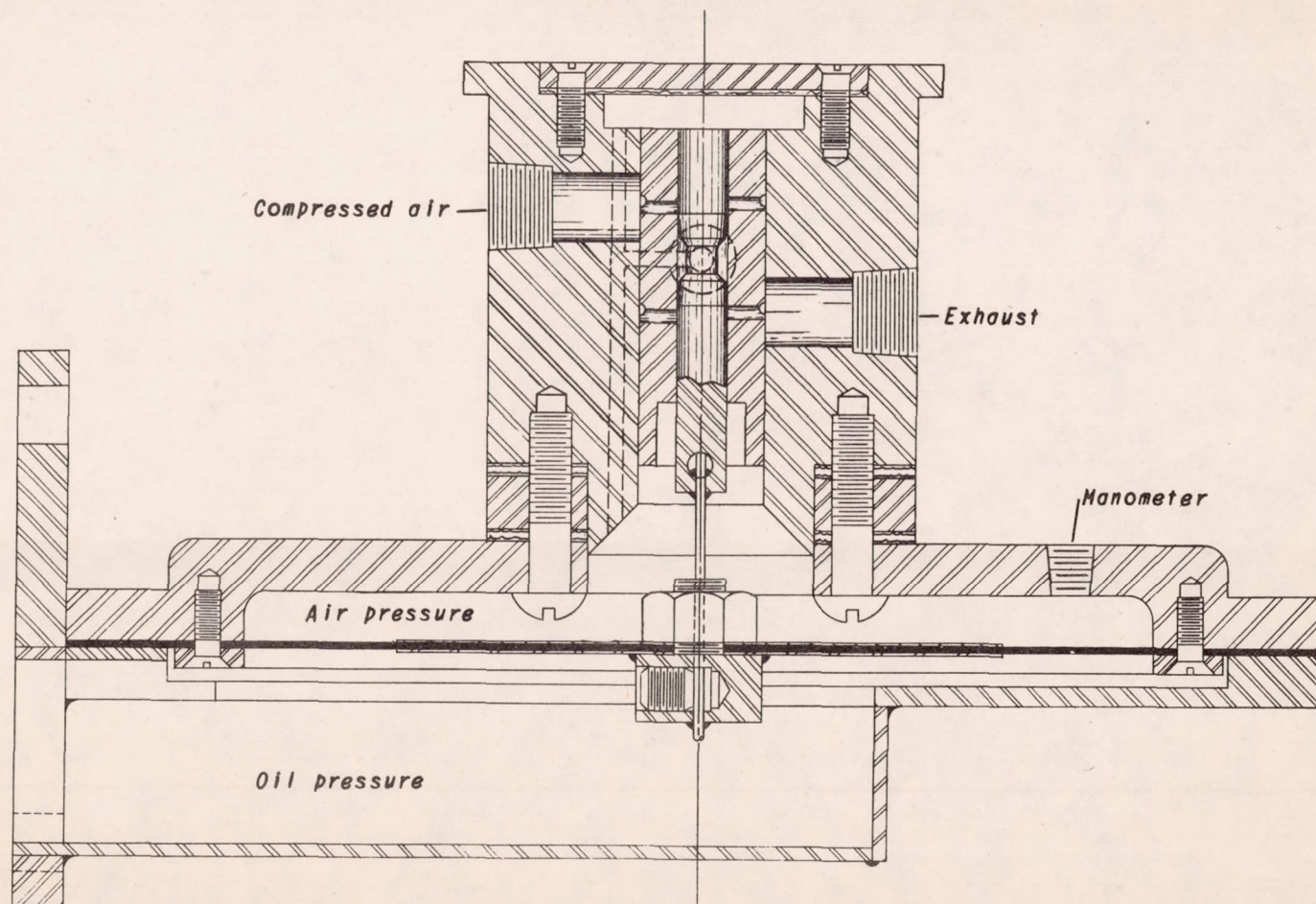
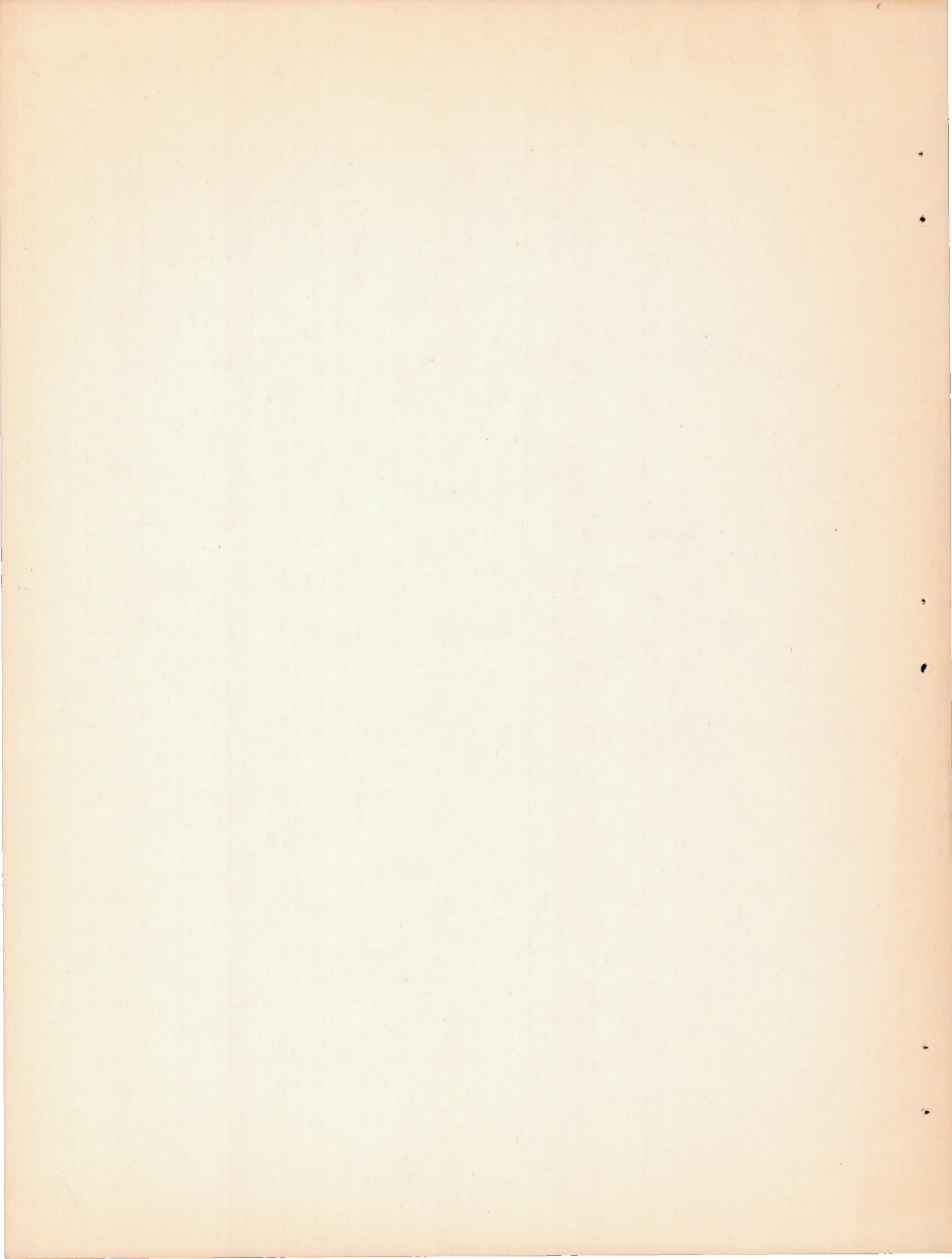


Figure 6. - Weighing-diaphragm assembly, balanced-pressure piston-ported spool-valve type. Effective area, approximately 10 square inches.



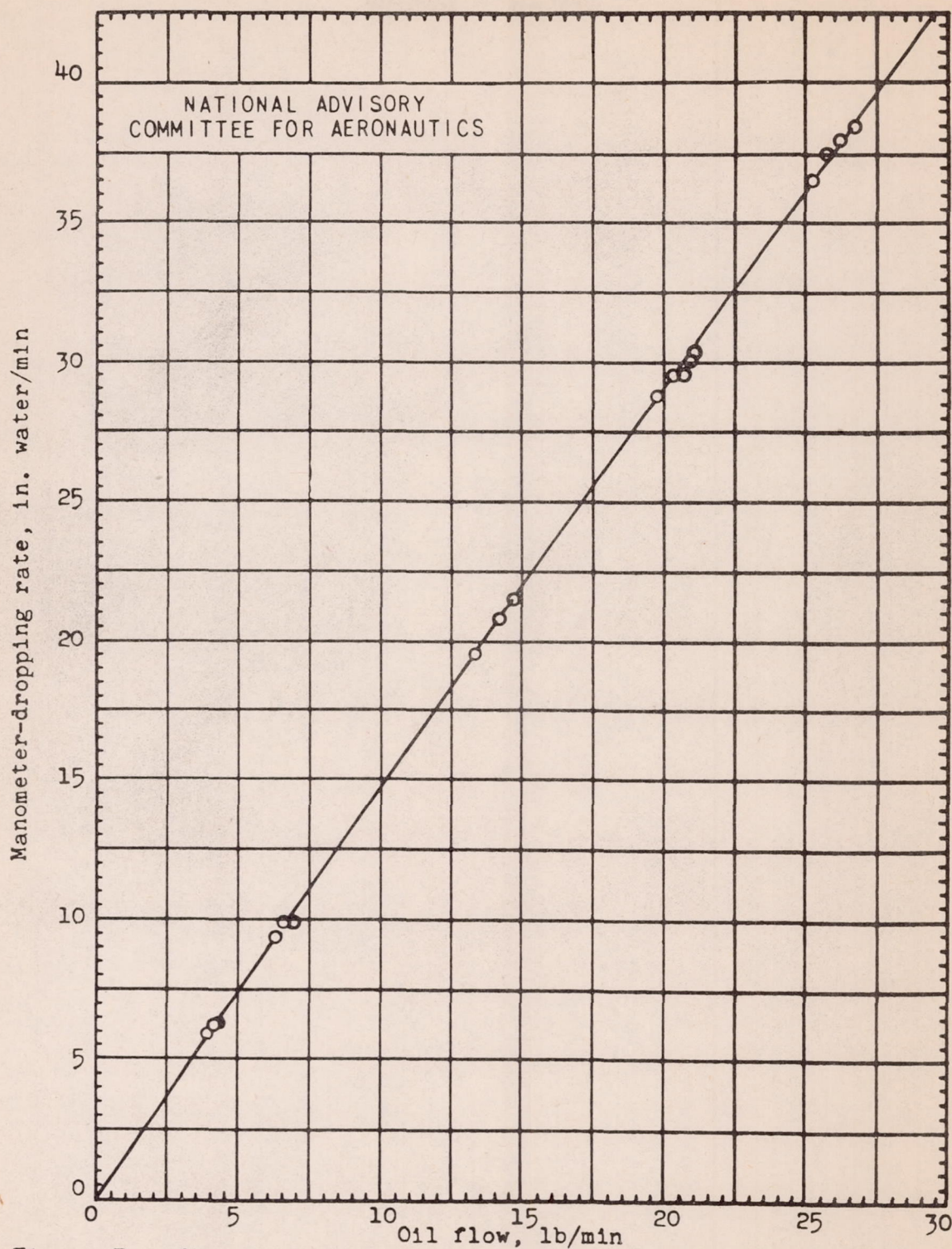
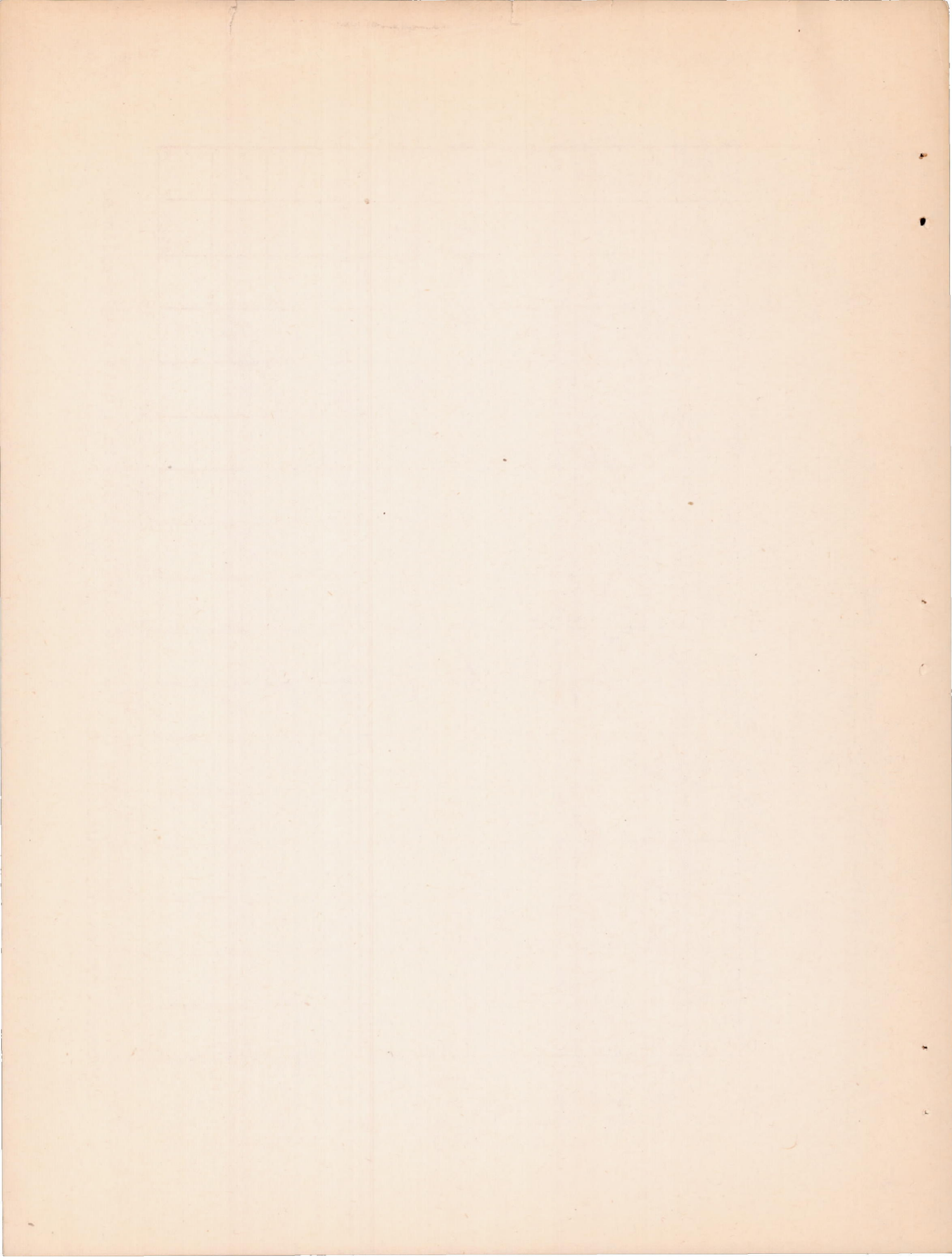


Figure 7. - Manometer-dropping rates for various oil-flow rates in a unit single-cylinder-engine oil system and weighing tank.



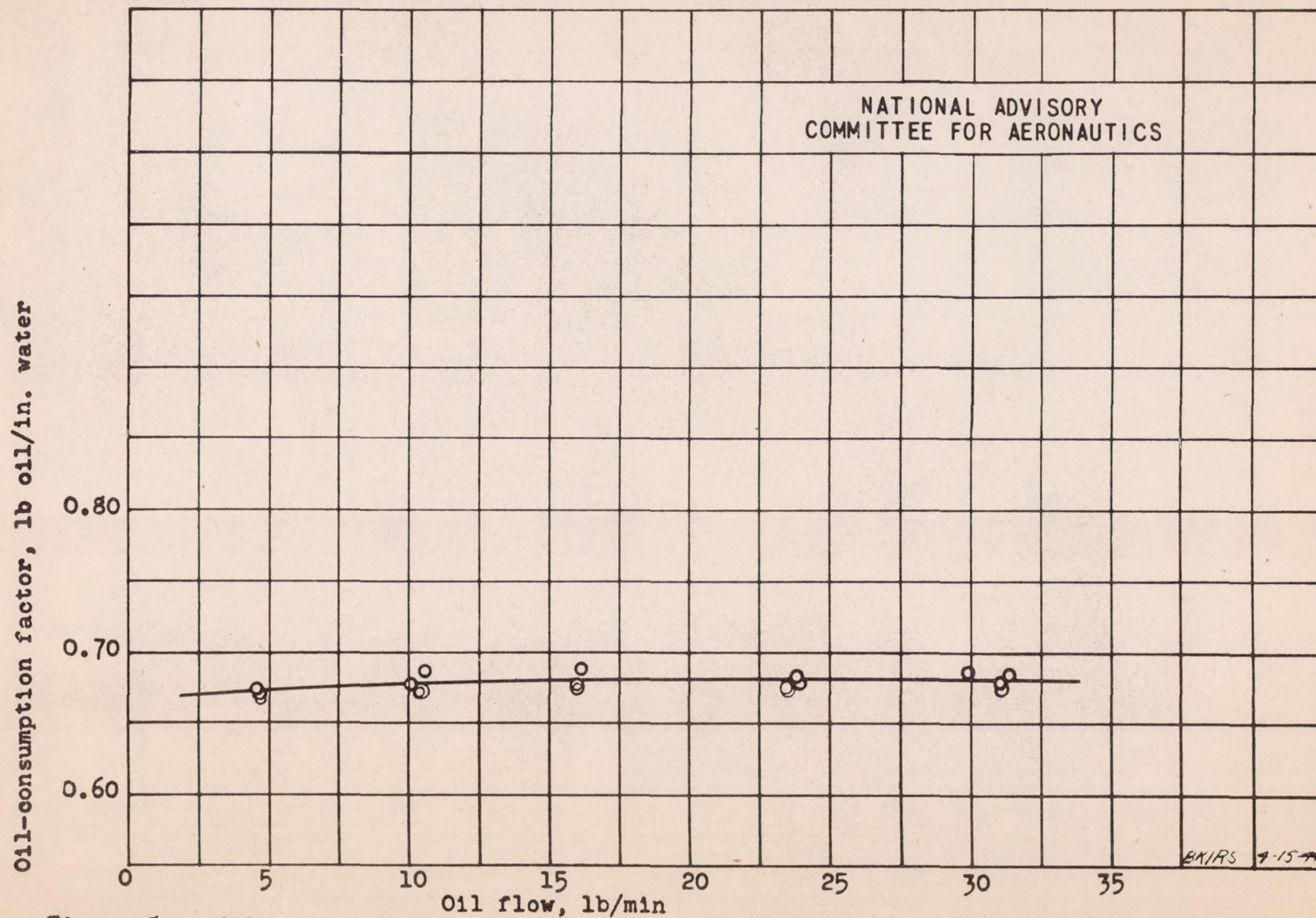


Figure 8. - Oil-consumption factor for various oil-flow rates in a unit single-cylinder-engine oil system and weighing tank.